

552 CD-116

3 December 1964

REPORT ON STEPPING DRIVE ON MODEL 552 SYSTEMSTEPPING MOTOR

The reason for the selection of stepping motor drive instead of a variable speed D.C. motor drive is to allow very good correspondence of the right and left hand channels. Thus, in a variable speed D.C. motor, the time required to get up to speed is dependent on many non-controllable parameters such as friction, damping, and time constants which affect the angular motion required to get up to the speed selected by the joystick. It is then possible in a D.C. drive to get out of stereo synchronism how left to right formats, especially after a few starts and stops. The stepping motor on the other hand has an incremental motion which is independent of friction, inertia and its own time constant, as long as its rated torque is not exceeded.

PRESENT CONFIGURATION OF DRIVE

The motor selected is SLO-SYN, SS400-1021, having 200 pulses per revolution (1.8 degrees per step). The torque is 400 ounce inches at start. The screw used is 2.5mm pitch. A gear drive is provided with a selection of:

1. High Speed: Step Up: 5.6 to 1  
each step =  $\frac{2.5\text{mm} \times 5.6}{200} = 0.7 \text{ micron}$
2. Low Speed: An addition stepping down by 100:1 to the above where each step =  $0.7 \times 100 = 70 \text{ microns}$

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A PULSE GENERATOR IS PROVIDED TO ACHIEVE THE FOLLOWING SPEEDS

Slow Pulse Generator: 3 to 60 pulses per second  
Fast Pulse Generator: 15 to 300 pulses per second

THE FOLLOWING COMBINATION IS PROVIDED

1. Fast Gear Fast Motor:  
70 microns/step x 300 pps (maximum speed)  
21,000 microns/second = 0.84 inch/second  
Minimum Speed: 1,050m/second = .042 inch/second
2. Fast Gear Slow Motor:  
210 microns/second to 4,200 microns/second  
0.008 inch/second to 0.17 inch/second
3. Slow Gear Fast Motor:  
10m/second to 210m/second  
.0004 inch/second to .008 inch/second
4. Slow Gear Slow Motor:  
2.1m/second to 42m/second  
.00008 inch/second to .0017 inch/second

VISIBILITY OF STEPS

The stepping rates will appear as a continuous motion to the eye in one of two conditions:

1. The angular displacement per step is less than the resolving capability of the eye.
2. The stepping rate is too fast for the eye to perceive as discrete steps but appears as continuous motion.

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The threshold value for the capability of the eye to resolve a step is dependent on several parameters, such as brightness, object size, and the presense of a fixed object such as a reticle in the field of view.

It is estimated that if a reticle is present, then the eye can perceive a motion as small as 0.4 milliradian (0.1mm at 10 inches). However, when a reticle is not present, then the eye is estimated to perceive 0.6 milliradian motion or (0.15mm at 10 inches). The value of the above is limited by the resolving capability of the eye. It is recognized that for the purpose of measurement, the eye can center to better than its resolving limit.

L The threshold rate for observation of steps (when each step is larger than one milliradian) is also dependent on brightness, the size of each step, and the instantaneous speeds of the image motion. It is however known that at 15 pulses per second the eye observes the stepping function as a continuous motion. If on the other hand the carriage never actually stops at 15 pulses per second, but continuously moves slightly in between pulses, then the eye may not perceive motion at stepping rates as low as 6 pps. Furthermore, if a reticle, or dot, is not present in the field of view, the eye may not perceive 10 pps, since there is no fixed frame of reference. 7

For the purpose of analysis, it is assumed that the rate of 15 pps is not perceivable by the eye; in addition, incremental motion below 0.6 milliradian will appear as continuous motion even at pulse rates of 4 pps.

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GRAPHICAL ANALYSIS

The analysis shown here are for the two images are approximately the same magnification, so that the switch is in the "Couple" mode.

Graph 1 depicts the angular subtension of each step, at different magnifications of the objective. This plot is made on log-log paper, showing that a magnification of 125X, a 2 micron motion appears as one milliradian of angular motion; as the magnification decreases, the 2 micron step appears smaller (being only 0.2 milliradians at 25X).

Graph 2 depicts the angular speeds versus linear speeds for different magnifications. On this graph is superimposed two speeds: the first is the angular rate of 15 milliradians per second, and the other is 100 milliradians per second. These two speeds are considered as a necessary requirement for a stereo viewer. The first represents a low speed necessary to enable the operator to set the stereo overlap to the desired value, optimum for stereo vision. Due to the extremely fast response of the stepping motor, this speed of 15 micron/second enables the operator to set the image to 3 milliradians or better with the joystick. The maximum required speed of 100 milliradians per second allows adequate scanning of images. This represents a motion of 6 degree/seconds, or 1 inch/seconds at 10 inches viewing distance (direct viewing). These two values 15-100 micron/seconds are presented as adequate minimum and maximum values of speeds for scanning and stereo observation. However, slower speeds and faster speeds are desirable to allow the operator flexibility for rapid scan, and very slow scan for precise pointing.

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ANALYSIS OF PRESENT SYSTEM

Graph 2 illustrates the operation of the present system with the four (4) speeds. The upper portion of the graph illustrates the region of operation of the fast gear from 15 pps to 300 pps. These repetition rates cannot be observed by the eye as pulses, but are essentially continuous motion. The fast gear - slow motor mode has an operation range from 3 pps to 15 pps where the eye observes the stepping rates and the upper portion of 15 to 60 pps in which it appears as continuous motion. In the slow gear mode where each pulse represents .7 microns the eye cannot distinguish such a small pulse under all magnifications, and consequently, over the full range of speeds of the slow gear it appears as continuous motion. One may conclude from this graph that the operation may be quite adequate at the slow gear at the very high magnifications. It is also apparent that the system is adequate at the fast gear for the very low magnifications. At the middle magnifications there is a gap where it is not possible to scan without the eye observing the motion as a stepping action.

POSSIBLE ALTERNATE APPROACH

In order to provide a system where the stepping action is not observable to the eye for all magnifications, it is possible to introduce a third gear where each step represents 7 microns.

Graph 3 illustrates the angular rate observed by the eye due to this additional gear. The hatched portion represents the region where the eye cannot observe the stepping action of the motor. The lower section of the graph illustrates that even at pulse rates lower than 15 pps, the eye cannot observe the pulsing motion when the magnification is below 20X.

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Graph 4 illustrates the combination of the three (3) gears. These are; fast, medium, and slow. The regions shown are only for fast motor mode. Thus, the operator is required to select only one of three speeds, depending upon his magnification for the purpose of scanning. The region of operation where the stepping motor goes below 15 pps would only be required when measurements are being made. The above addition of a third gear would resolve the problem of observing steps in all magnifications for the "Couple" mode only. However, it must be realized that in the "Decouple" mode where the magnifications of the right hand channel may be quite different from the magnification of the left hand channel, then the steps may be observable to the eye. As an example, if the operator desires to observe the left hand channel at 4X and the right hand channel at 40X due to image size ration of 10:1, then the medium speed will have to be used to obtain 40 milliradians per second. The lowest speed he can scan without observation of the steps is about 17 milliradians per second, below which the stepping rates for the right hand channel would be below 15 pps. If he now switches over to the slowest gear, then the maximum speed possible is 5 micron/seconds at 375 pps.

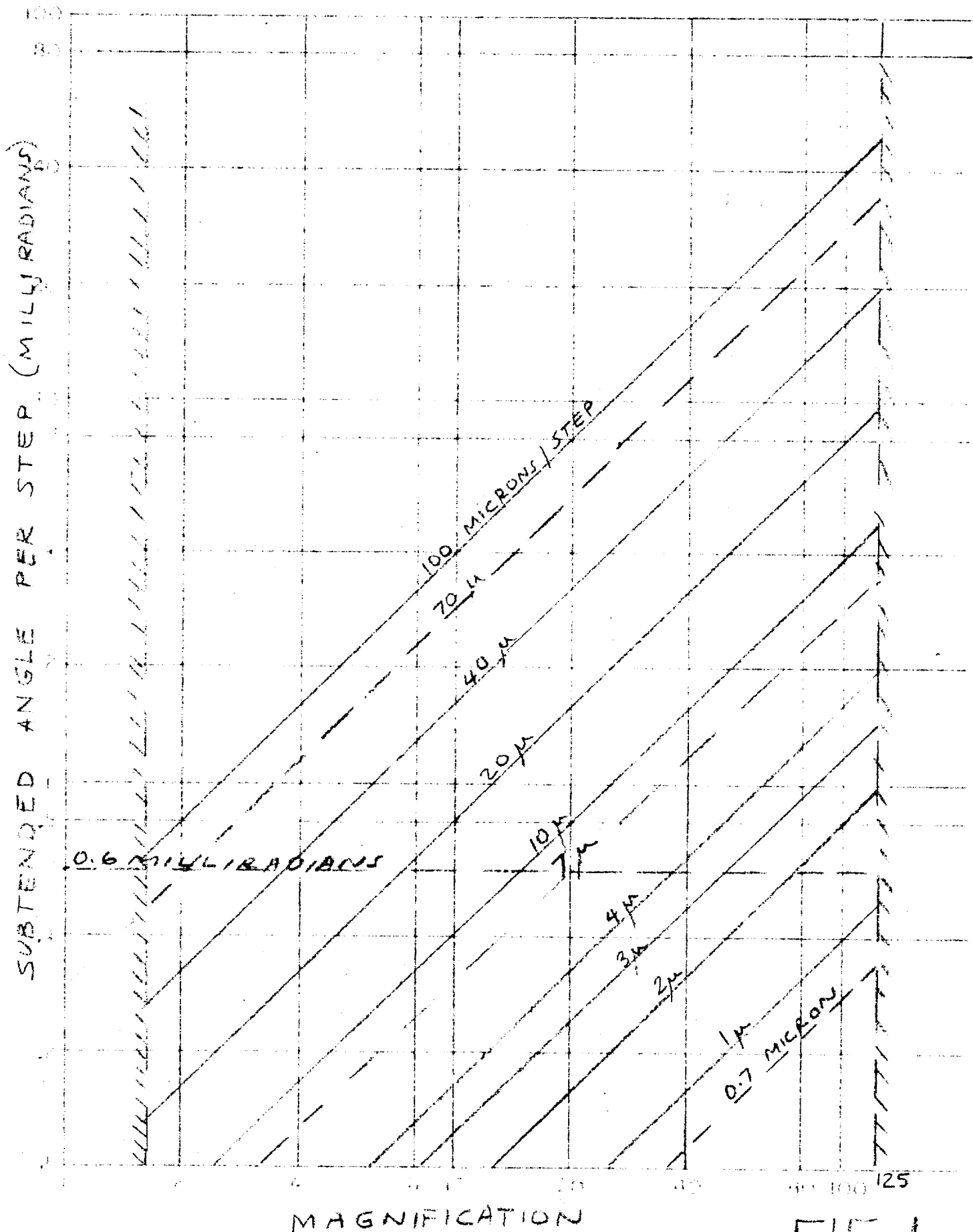
#### POSSIBLE USE OF OTHER MOTORS

The use of pulse motors with higher stepping rates had been investigated in the first phase of design. The only possible motor available at that time was made by  in which the manufacturer claims that it could go to 1200 pps. However, the analysis at that time had indicated that these high pulsing rates presented limitations on the available torque of the motor. This was caused mainly by the inertia that is observed by the motor. The inertial forces required to accelerate to 1200 pps without skipping would have resulted in loss of step of the motor. Furthermore, the increased size of this motor would have resulted in some design problems.

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Investigation was also made in the beginning of the program for the use of DC motors. However, it was found difficult, if not impossible, that the right and left hand carriages can be made to synchronize with each other, especially under different torque conditions. Even though it is possible to obtain DC motors, such as PMI, with very precise velocity control, it was not possible to assure that the acceleration and deceleration rates of the right hand and left hand motors would stay in correspondence.





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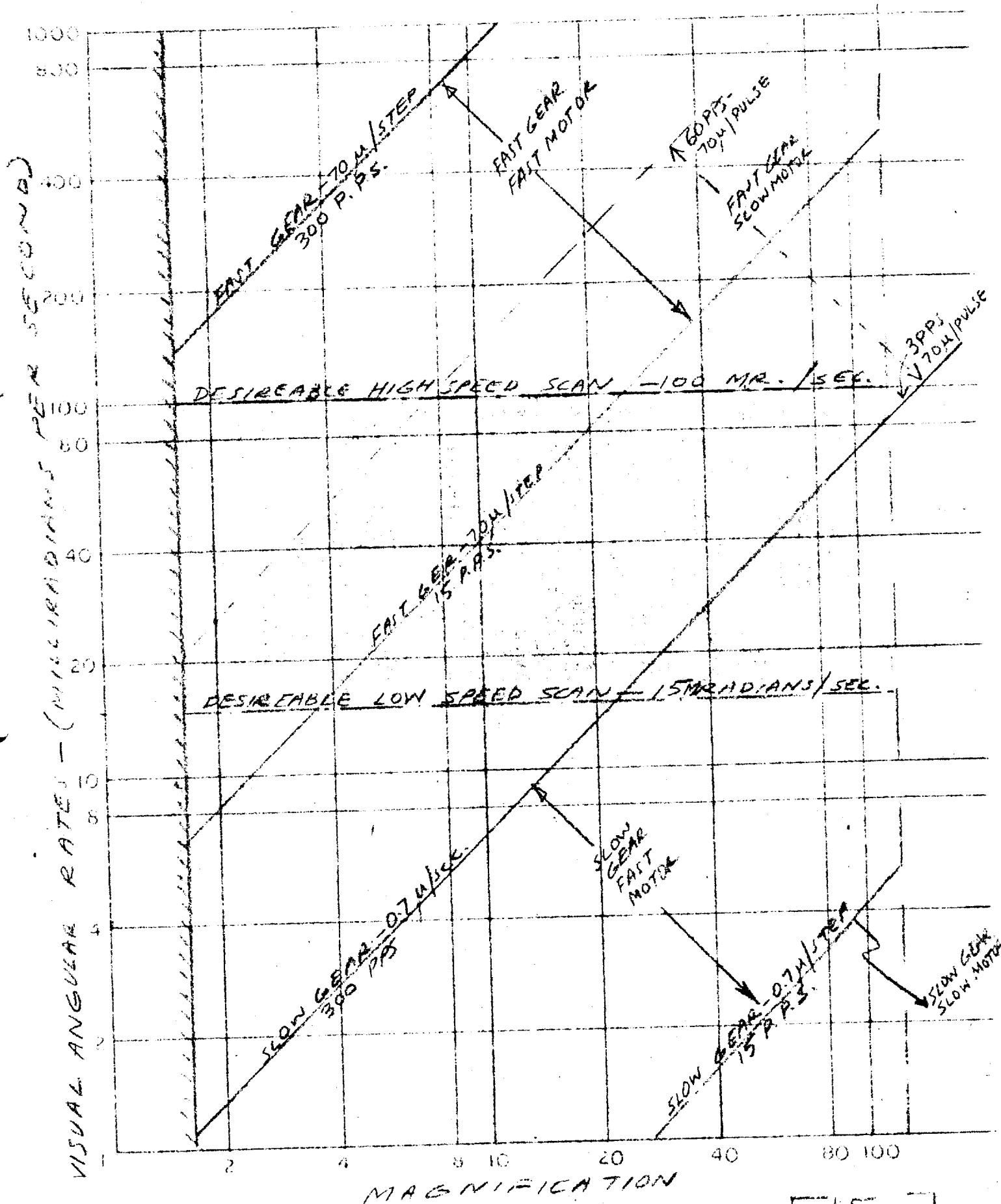
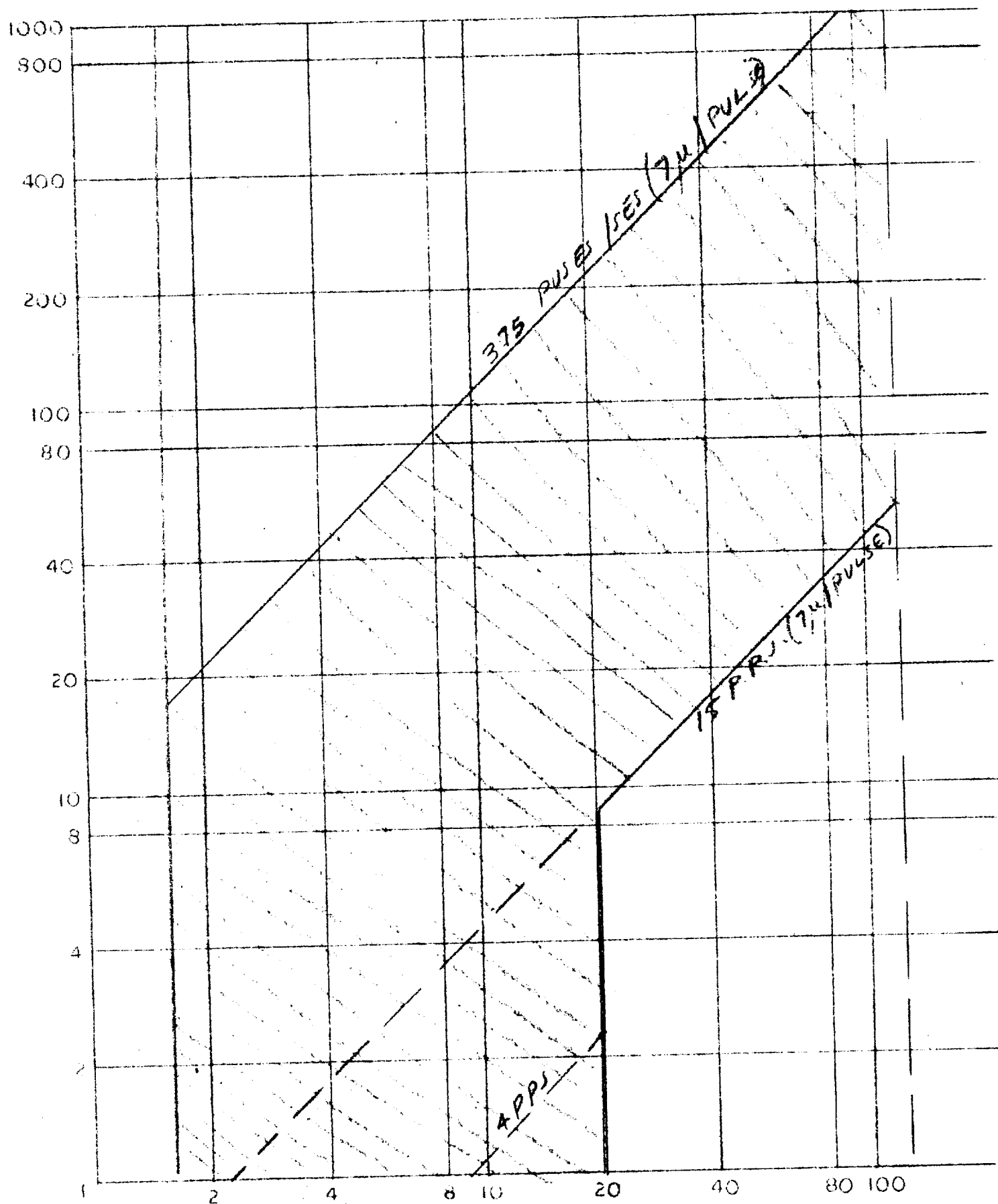


FIG. 2

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— MAGNIFICATION —

